Reducing Ultra-Clean Transportation Fuel Costs with HyMelt® Hydrogen

Quarterly Report

January 1 – March 31, 2003

April 30, 2003

Work Performed Under Cooperative Agreement No. DE-FC26-02NT41102

For
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 10940
626 Cochrans Mill Road
M/S 922-273C
Pittsburgh, PA 15236-0940

By
Donald P. Malone and William R. Renner
EnviRes LLC
1509 Bull Lea Drive
Suite 500
Lexington, KY 40511

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ABSTRACT

This report describes activities for the second quarter of work performed under this agreement. Kick off meetings with MEFOS, Kvarner and Siemens Westinghouse were held during the reporting period. MEFOS and Kvaerner have completed initial computational simulations. MEFOS has drafted a detailed experimental test plan and is making preparations for atomospheric testing, scheduled to begin on Jume 5.

TABLE OF CONTENTS

1.0 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1.1 Introduction

EnviRes and DOE executed the cooperative agreement for this work on September 19, 2002. This document is the second quarterly progress report under this agreement.

1.2 Scope of Work

Phase I of the work to be done under this agreement consists of conducting atmospheric gasification of coal using the HyMelt technology to produce separate hydrogen rich and carbon monoxide rich product stream. In addition smaller quantities of petroleum coke and a low value refinery stream will be gasified. DOE and EnviRes will evaluate the results of this work to determine the feasibility and desirability of proceeding to Phase II of the work to be done under this agreement, which is gasification of the above-mentioned feeds at a gasifer pressure of approximately 5 bar. The results of this work will be used to evaluate the technical and economic aspects of producing ultra-clean transportation fuels using the HyMelt technology in existing and proposed refinery configurations.

1.3 Phase I Task Description

Task 1.1 Project Management and Planning

This task includes all project planning; experimental test plans; risk analysis; implementation of a bridge loan, purchasing, contracting and accounting systems with requisite auditing; and execution of contracts with MEFOS, Kvaerner and Siemens Westinghouse;

Task 1.2 Preparation and Shipment of Feedstock Materials

This task consists of procuring 25 tons of coal, 15 tons of petroleum coke and 48 – 55 gal drums of Aromatic extract oil; transporting the coke and coal to a pulverizing facility; pulverizing, drying and loading the coke and coal into bags; and shipping the feedstocks to MEFOS in Lulea, Sweden.

Task 1.3 Predictive Modeling of the HyMelt Process

This task consists of generating detailed reactor energy and material balances for each feedstock using the FACT pyrometallurgical thermodynamic modeling program. Kvaerner will perform detailed process simulation using the Aspen Plus process simulator. Kvaerner, MEFOS and EnviRes will evaluate and analyze the results of predictive modeling.

Task 1.4 Combustion Modeling and Analysis

Siemens Westinghouse will perform combustion turbine modeling using fuel gas conditions and compositions provided by task 1.3.

Task 1.5 Design and Fabrication of Pilot Plant Specific Molten Iron Bath Apparatus

MEFOS will design and fabricate all solid feeding systems and oxygen injection systems required by the testing. EnviRes will assist MEFOS in designing the petroleum liquid feed system. MEFOS will design the shell of the high-pressure reactor.

Task 2.0 Project Testing

Task 2.1 HyMelt Atmospheric Pressure Testing in a Molten Iron Bath

MEFOS will fabricate the petroleum liquid feed system. All injection systems will be tested in a cold flow environment. The injection systems will be hot commissioned. Any equipment revisions indicated by cold flow testing and hot commissioning will be made. Process performance testing will be performed for each feed.

2.0 EXECUTIVE SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

An audit of the financial reporting and accounting system of EnviRes was conducted by Brad Quinlan, auditor for the Defense Contract Audit Agency (DCCA) under contract by U. S. Department of Energy. The audit was conducted on January 15 and 16 and an exit conference was held on January 17 with the auditor, Tom Ward, President; Don Malone, Chief Technical Office; Bill Renner, Chief Financial Officer; and Dan French, Controller. Five areas of deficiencies were identified. During the exit conference all deficiencies were fully discussed and specific remediation of the deficiencies were outlined by EnviRes staff with the auditor. A follow-up call to Mr. Andrew Ferlic, Contracting Officer for DCCA, indicated that our remediation steps were acceptable.

In late March we received verbal notification that the Cooperative Agreement had received full funding and that an Amendment would be forthcoming. On April 4, Amendment A003 was executed obligating the DOE for an additional funding of $1,424,812.00 for a total DOE project funding of $1,824,812.00. In addition, the amendment requested another audit to verify the implementation of the remediation measures identified in the January audit and exit conference. A request to schedule the audit has been made to DCCA.

Marathon Ashland Petroleum loaded 50 drums of 325 aromatic extract oil on January 10. The drums were loaded into a Sea Land container that left Savannah, GA on January 22. MEFOS received the oil in mid February. MEFOS has stored the oil on site. MEFOS executed the subcontract with EnviRes on January 27. D. P. Malone met with MEFOS at their offices in Lulea, Sweden from February 24 to 28.

EnviRes met with Siemens Westinghouse at their offices in Pittsburgh, PA. We discussed issues outstanding in their subcontract agreement and toured their facility. We still have not executed a subcontract with Siemens Westinghouse, but most major issues have been resolved. We expect to execute an agreement in May.

D. P. Malone met with Kvaerner on February 6 to finalize the objectives for Kvaerner for their work up to the decision point. A process flow diagram for the Aspen Plus simulation was developed. We established Objectives for Kvaerner up to the decision point. Kvaerner will make an economic comparison of shifting some or all of the CO rich stream to produce more or all hydrogen. Kvaerner will investigate and compare methods of slag removal from HyMelt reactors. Kvaerner will perform a refractory survey and develop criteria for refractory selection.

EnviRes and MEFOS held a kick off meeting on February 24 to 28. Planning and preparations for the experimental test program is underway. Experimental testing at atmospheric pressure will begin on June 5 and last through June 13. MEFOS will perform approximately 8 hours of feedstock injection/oxygen blowing during each test day. MEFOS will perform an additional 2 hours of start up and 2 hours of shutdown activities on each test day.

3.0 Experimental

D. P. Malone met with MEFOS in Lulea, Sweden from February 24 to 28 to define the objectives and methods of the test program. The liquid feed system was reviewed and project objectives were established. We developed and subsequently revised a proposed process flow diagram (PFD) for the liquid feed system. EnviRes accepted a final PFD for the liquid feed system. The finalized PFD, Figure 1 appears at the end of this section.

We established guidelines for the thermodynamic simulation. MEFOS performed two iterations of the hydrogen production step and two iterations of the carbon monoxide production step using Fact Sage thermodynamic simulation software.Results of this simulation appear in Appendix I. The first four tables, Table AI-1 to AI-4 show results from coke injection. The initial conditions started with 0.5 wt% C in the metal, 1.25 wt% S, Coke injection rate of 100 Kg/min, metal in bath of 10,000 Kg, metal temperature of 1550°C and pressure of 20 bar. The oxygen injection started with metal containing 4/06 wt% C, 1.46 wt% S and an oxygen injection rate of 21 Nm/min.

The solids feed system will be very similar to solids feed systems used by MEFOS in previous gasification tests. Existing lances, hoppers and transport gas systems will be used. Figure 2 is a photograph of a solids feed hopper. It is rated for a pressure of 15 bar. Note that a load cell is attached to the ends of each of the 4 legs. This allows a continuous measurement of the weight of solids in the hopper.

Instrumentation and sampling procedures were reviewed and accepted. Figure 3 shows a dual flow meter run for Oxygen. This allows for a greater range of flows with acceptable measurement accuracy. Reactor effluent gases will be sampled several times during an injection cycle. Isokinetic for dust loading and particle characterization will be performed. A quadrapole mass spectrometer will allow gas analysis every 30 seconds during an injection cycle. The instrument has a detection threshold for COS,Hg and HCH in the range of 100 ppb. Figure 4 shows a typical instrument cabinet at MEFOS used for gas analysis. A draft of the detailed test plan appears in Appendix II

Kvaerner began assembling the flow sheet for the Aspen Plus simulation of the HyMelt process. Output from the Fact Sage simulation performed by MEFOS will be the input for the Aspen Plus simulator. The Aspen Plus simulator will simulate everything but the reactors for the HyMelt process.

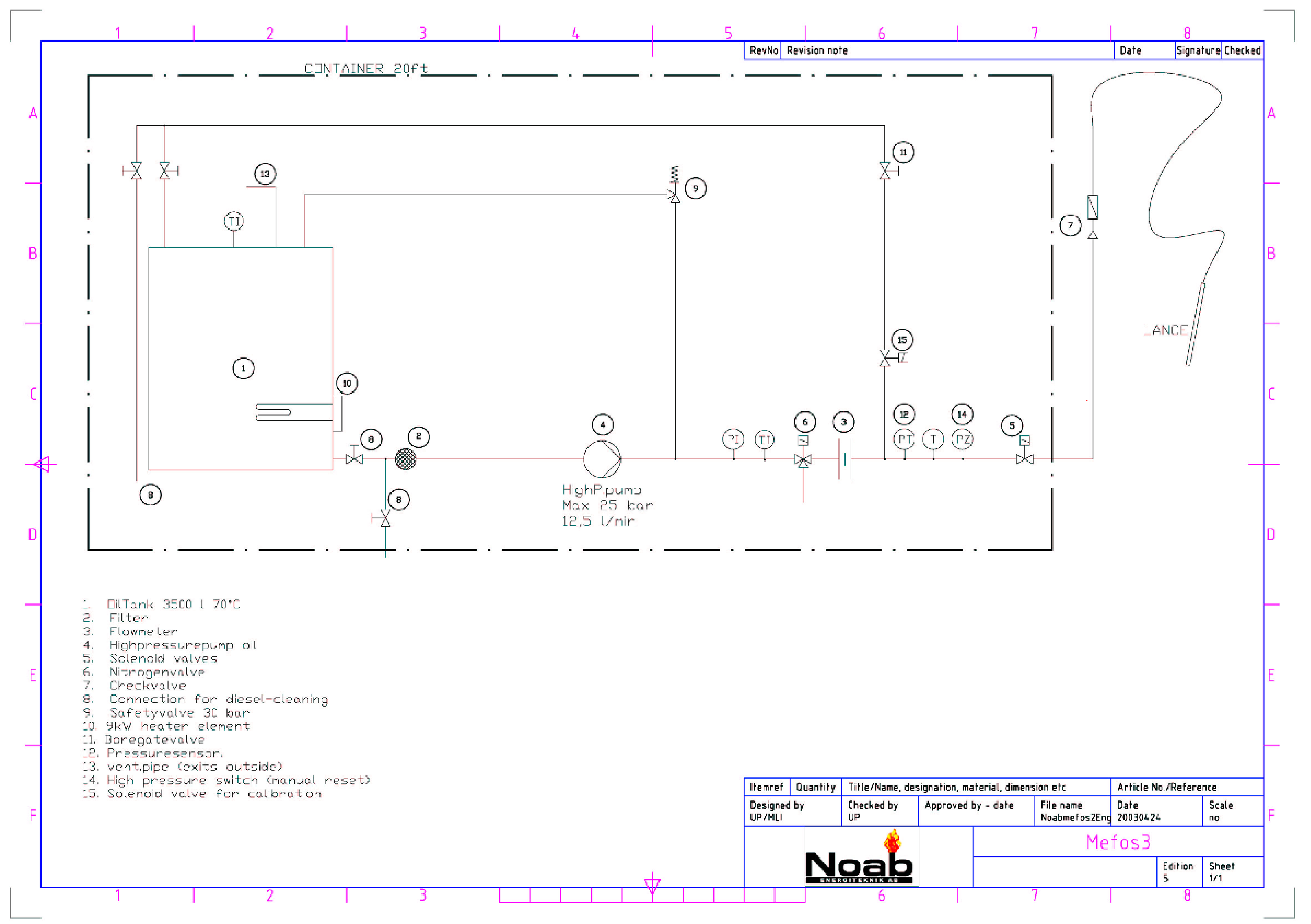

Figure 1. Liquid Feed PFD for MEFOS Testing

Figure 2 Solids Feed Hopper at MEFOS

Figure 3. Dual Flow Meter Run for Oxygen

Figure 4. A Typical Analytical Instrument Cabinet at MEFOS

4.0 Results and Discussion

Results of the first Fact Sage pyrometallurgical thermodynamic simulation appear in Appendix I. The first four tables, Table AI-1 to AI-4 show results from coke injection. The initial conditions started with 0.5 wt% C in the metal, 1.25 wt% S, Coke injection rate of 100 Kg/min, metal in bath of 10,000 Kg, metal temperature of 1550°C and pressure of 20 bar. The oxygen injection started with metal containing 4/06 wt% C, 1.46 wt% S and an oxygen injection rate of 21 Nm/min.

The mol fraction of hydrogen in the product gas from coke injection ranges from 97% to 94.5% over the injection. Molecular nitrogen, N2, averages approximately 1 mol%, the CO level is fairly constant at 2 mol%, CO2 is less than 1ppm, methane averages to less than 1mol%, HCN ranges from 27 to 740 ppm and COS 1.4 to 4.4 ppm. During oxygen injection the CO concentration is generally in the 95 mol% range and CO2 around 1 mol% although the CO2 level rises rapidly at the end of the injection to as high as 13.5 mol%. This indicates that the oxygen injection endpoint should be moved to 0.7%w carbon instead of 0.5%w carbon in the metal. COS ranges from 3 to 47 ppm. HCH ranges from 429 to 0.08 ppm.

5.0 Conclusion

Results from the Fact Sage simulation are generally what were expected. The Fact Sage simulation allows for a much more detailed examination of gas compositions for incremental injection. The simulation shows that the carbon level at the end of oxygen should be increased to 0.7%w. If experimental testing bears out this indication, the endpoint will be changed. The levels of COS and HCH are fairly low, however we must examine further the consequences of these levels on product quality and process configuration.

Additional studies are in progress. We will make both injections adiabatic. Hydrogen recycle and or lime injection will be added to maintain a constant sulfur level in the metal when averaged over many cycles.

6.0 References

No references were cited in this document.

7.0 PLAN FOR THE NEXT QUARTER

We plan to continue predictive modeling as described in task 1.3 with both Kvaerner and MEFOS. EnviRes will probably not lease the Aspen Plus process simulation package.

MEFOS is designing and fabricating the molten iron bath apparatus as described in task 1.5. Atmospheric testing will begin on June 5. We plan to execute the Siemens Westinghouse agreement and begin work on combustion turbine evaluation.

APPENDIX I

Results of Initial Fact Sage Simulation

Table AI-1. Cumulative mols of gas produced during coke injection

Inject time,min	T(C)	P(bar)	Mol-H2(g)	Mol-CH4(g)	Mol-C2H2(g)	Mol-N2(g)	Mol-HCN(g)	Mol-H2O(g)	Mol-CO(g)	Mol-CO2(g)	Mol-H2S(g)	Mol-COS(g)
0	1550	20	0	0	0	0	0	0	0	0	0	0
1	1550	20	2.03909	0.00191377	2.65208E-06	0.00652992	5.77792E-05	0.00322373	0.0477859	1.9648E-05	0.00359431	2.96111E-06
2	1550	20	4.52199	0.00994221	3.26708E-05	0.03370162	0.000460712	0.00315243	0.110807	2.009E-05	0.01018364	8.77235E-06
3	1550	20	6.970525	0.0293259	0.000186217	0.06891812	0.001572897	0.002545	0.1728619	1.64142E-05	0.01935137	1.68702E-05
4	1550	20	9.371745	0.067114	0.000732579	0.1054866	0.003859673	0.00200209	0.2337596	1.29876E-05	0.03112794	2.72945E-05
5	1550	20	11.70944	0.1316098	0.002280309	0.1414196	0.007884535	0.00158332	0.2934402	1.03193E-05	0.04537399	3.99729E-05
6	1550	20	14.08407	0.1759242	0.003402021	0.175816	0.01073797	0.00171416	0.3545737	1.12235E-05	0.05933386	5.25117E-05
7	1550	20	16.48762	0.2058285	0.003982598	0.2100573	0.01269921	0.00201247	0.41652	1.32223E-05	0.07370621	6.54572E-05
8	1550	20	18.89007	0.2357042	0.004562913	0.244377	0.01466141	0.00231069	0.4784777	1.52219E-05	0.08920549	7.94319E-05
9	1550	20	21.29147	0.2655528	0.005142973	0.2787497	0.01662413	0.0026088	0.5404424	1.7222E-05	0.1057944	9.44022E-05
10	1550	20	23.69186	0.2953753	0.005722789	0.3131599	0.01858709	0.0029068	0.6024119	1.92224E-05	0.1234374	0.000110336
			Major gaseous species in cumulative kmol									

Table AI-2.Metal composition in Wt% during coke injection

Inject time,min	T(C)	P(bar)	Wt%-Fe	Wt%-C	Wt%-H	Wt%-N	Wt%-Ni	Wt%-O	Wt%-S	Wt%-Si	Wt%-V
0	1550	20	99.009901	0.49504965	0	0	0	0	0.4950497	0	0
1	1550	20	98.094885	1.3311671	0.008509363	0.00799841	0.00039238	0.001796892	0.5530923	0	0.00215779
2	1550	20	97.216028	2.1498584	0.007926846	0.010173212	0.000777728	0.001710053	0.6092479	0	0.00427735
3	1550	20	96.356631	2.9528031	0.007529274	0.010040779	0.00115628	0.001857329	0.6636229	0	0.00635947
4	1550	20	95.515433	3.7395562	0.007264215	0.009392396	0.001528247	0.002168615	0.7162518	0	0.00840532
5	1550	20	94.692575	4.5094582	0.00709697	0.008694501	0.001893852	0.002639613	0.7672257	0	0.01041617
6	1550	20	94.442861	4.7016229	0.007060365	0.008617966	0.002266629	0.002817398	0.8222873	0	0.01246644
7	1550	20	94.389651	4.6957928	0.007052448	0.008718372	0.002642911	0.002852017	0.8787541	0	0.01453599
8	1550	20	94.336833	4.6900049	0.007044822	0.008797831	0.003018779	0.002884766	0.934813	0	0.01660327
9	1550	20	94.28439	4.6842541	0.007037401	0.008863176	0.003394238	0.002916271	0.9904761	0	0.01866829
10	1550	20	94.232308	4.6785404	0.007030132	0.008918548	0.003769293	0.002946912	1.0457558	0	0.02073108
			Metal composition in wt%								

Table AI-3. Gas composition in mol fraction during coke injection

Inject time,min	T(C)	P(bar)	X-H2(g)	X-CH4(g)	X-C2H2(g)	X-N2(g)	X-HCN(g)	X-H2O(g)	X-CO(g)	X-CO2(g)	X-H2S(g)	X-COS(g)
0	1550	20	0	0	0	0	0	0	0	0	0	0
1	1550	20	0.969825	0.0009102	1.261E-06	0.00310574	2.7481E-05	0.001533257	0.02272776	9.34493E-06	0.0017095	1.40835E-06
2	1550	20	0.963947	0.0021194	6.964E-06	0.00718413	9.8209E-05	0.000671999	0.02362059	4.28257E-06	0.0021708	1.86999E-06
3	1550	20	0.959234	0.0040356	2.563E-05	0.00948402	0.00021645	0.000350224	0.02378801	2.2588E-06	0.002663	2.32156E-06
4	1550	20	0.954532	0.0068357	7.461E-05	0.01074404	0.00039312	0.000203917	0.02380891	1.32282E-06	0.0031704	2.78E-06
5	1550	20	0.949158	0.0106682	0.0001848	0.01146335	0.00063911	0.000128343	0.02378602	8.36474E-07	0.003678	3.24017E-06
6	1550	20	0.947127	0.0118306	0.0002288	0.01182328	0.00072211	0.000115274	0.02384439	7.54755E-07	0.0039901	3.53131E-06
7	1550	20	0.946582	0.011817	0.0002286	0.01205975	0.00072908	0.00011554	0.02391313	7.59113E-07	0.0042316	3.75801E-06
8	1550	20	0.946117	0.0118053	0.0002285	0.01223972	0.00073432	0.000115732	0.02396474	7.62393E-07	0.0044679	3.97838E-06
9	1550	20	0.945706	0.0117951	0.0002284	0.01238126	0.0007384	0.000115876	0.0240049	7.6495E-07	0.0046991	4.19307E-06
10	1550	20	0.945335	0.0117859	0.0002283	0.01249548	0.00074165	0.000115985	0.02403701	7.66998E-07	0.0049253	4.40254E-06

Gas composition in molefraction

Table AI-4 Weight of species in metal phase during coke injection

Inject time,min	T(C)	P(bar)	g-Fe(FeLQ)	g-C(FeLQ)	g-H(FeLQ)	g-N(FeLQ)	g-Ni(FeLQ)	g-O(FeLQ)	g-S(FeLQ)	g-Si(FeLQ)	g-V(FeLQ)
0	1550	20	9999.9974	50.000002	0	0	0	0	50.000004	0	0
1	1550	20	9999.9974	135.70196	0.86746224	0.81537461	0.04	0.18317889	56.383383	0	0.2199692
2	1550	20	9999.9974	221.14232	0.8153845	1.0464539	0.07999999	0.17590236	62.669473	0	0.4399843
3	1550	20	9999.9974	306.44516	0.78139635	1.0420432	0.11999998	0.19275565	68.871519	0	0.6599925
4	1550	20	9999.9974	391.51319	0.76052766	0.98333783	0.15999997	0.22704333	74.988045	0	0.8799961
5	1550	20	9999.9974	476.22076	0.74947459	0.9181817	0.20000002	0.27875595	81.02277	0	1.0999982
6	1550	20	9999.9974	497.82711	0.74758037	0.91250561	0.24000001	0.29831762	87.067148	0	1.3199982
7	1550	20	9999.9974	497.49008	0.74716308	0.92365736	0.28000001	0.30215347	93.098538	0	1.5399978
8	1550	20	9999.9974	497.15509	0.74677301	0.93259744	0.32	0.30579413	99.093085	0	1.7599978
9	1550	20	9999.9974	496.82167	0.74640128	0.94004678	0.35999993	0.30930568	105.05194	0	1.9799973
10	1550	20	9999.9974	496.48993	0.74604245	0.9464424	0.39999992	0.31272827	110.97633	0	2.1999969

Metal phase in absolute amount, kg

Table AI-5. Cumulative mols of gaseous species produced during oxygen injection

lO2, min	T(C)	P(atm)	Mol-H2(g)	Mol-CH4(g)	Mol-C2H2(g)	Mol-N2(g)	Mol-HCN(g)	Mol-H2O(g)	Mol-CO(g)	Mol-CO2(g)	Mol-H2S(g)	Mol-COS(g)
0	1550	20	0	0	0	0	0	0	0	0	0	0
1	1550	20	0.2018438	0.000185774	0.000013992	0.00804208	0.000147282	0.001680874	1.354178	0.00293287	0.00065916	0.00015546
2	1550	20	0.2387454	0.000102867	1.26499E-05	0.01185142	0.000170002	0.002436422	3.204848	0.00850595	0.00075886	0.0003581
3	1550	20	0.2553095	6.6144E-05	1.02345E-05	0.01389631	0.00016558	0.003066183	5.0748	0.01585068	0.00079002	0.00055203
4	1550	20	0.2650251	4.55565E-05	7.93848E-06	0.01518195	0.000152425	0.00372541	6.943945	0.02538582	0.00079753	0.00073459
5	1550	20	0.2713694	3.25519E-05	5.99001E-06	0.01605172	0.000136144	0.004474284	8.806834	0.03776421	0.00079311	0.00090483
6	1550	20	0.275689	2.37461E-05	4.41583E-06	0.01665999	0.000119088	0.00535917	10.6601	0.05389361	0.00078137	0.00106212
7	1550	20	0.2786113	1.75157E-05	3.18333E-06	0.01708804	0.000102403	0.006430189	12.50036	0.07503181	0.00076458	0.00120593
8	1550	20	0.2804496	1.29782E-05	2.24245E-06	0.01738333	8.66867E-05	0.007749798	14.32337	0.1029387	0.00074397	0.00133574
9	1550	20	0.2813501	9.60991E-06	1.54088E-06	0.01757573	7.22547E-05	0.009400715	16.12336	0.1401094	0.00072027	0.00145104
10	1550	20	0.2813499	7.07944E-06	1.03009E-06	0.01768529	5.92609E-05	0.01149585	17.89212	0.1901314	0.00069389	0.00155125
11	1550	20	0.2803978	5.16622E-06	6.67628E-07	0.01772634	4.77641E-05	0.01419197	19.61774	0.2582348	0.00066507	0.00163575
12	1550	20	0.2783544	3.71776E-06	4.17723E-07	0.01771005	3.77641E-05	0.01770823	21.28274	0.3521294	0.00063386	0.00170373
13	1550	20	0.2749812	2.62539E-06	2.51065E-07	0.01764622	2.92242E-05	0.02234925	22.86119	0.4832329	0.00060022	0.0017542
14	1550	20	0.2699279	1.80976E-06	1.44215E-07	0.01754484	2.20854E-05	0.02852606	24.31508	0.6682939	0.00056395	0.00178584
15	1550	20	0.2627416	1.21154E-06	7.88656E-08	0.01741761	1.62728E-05	0.0367523	25.59063	0.9309672	0.00052483	0.001797
16	1550	20	0.2529478	7.84904E-07	4.10658E-08	0.01727894	1.16956E-05	0.04756318	26.61826	1.30172	0.00048277	0.00178592
17	1550	20	0.2402639	4.92441E-07	2.05227E-08	0.01714567	8.23605E-06	0.06129303	27.32347	1.812826	0.00043808	0.00175135
18	1550	20	0.224902	3.01334E-07	1.0019E-08	0.01703395	5.73579E-06	0.07775438	27.65318	2.48642	0.00039185	0.00169375
19	1550	20	0.207693	1.82138E-07	4.89113E-09	0.01695447	3.99826E-06	0.09609976	27.60417	3.321796	0.00034589	0.00161608
20	1550	20	0.1898054	1.10225E-07	2.43722E-09	0.01691017	2.81868E-06	0.1151126	27.22593	4.294324	0.00030209	0.00152328

Table AI-6 Metal composition in Wt% during oxygen injection

lO2, min	T(C)	P(atm)	Wt%-Fe	Wt%-C	Wt%-H	Wt%-N	Wt%-Ni	Wt%-O	Wt%-S	Wt%-V
0	1550	20	95.364977	3.8718171	0.006675547	0.008582845	0.001811934	0.002288748	0.73431005	0.009536461
1	1550	20	95.444737	3.7194194	0.002742788	0.006419679	0.001813451	0.080656825	0.7346663	0.009542891
2	1550	20	95.648257	3.5140825	0.002023232	0.005409742	0.001817318	0.082710198	0.7361341	0.009562631
3	1550	20	95.857447	3.305609	0.001696016	0.004873114	0.001821292	0.081296466	0.73767062	0.009582818
4	1550	20	96.0679	3.0960746	0.001499396	0.004539628	0.001825291	0.079324831	0.73922854	0.009602902
5	1550	20	96.278648	2.8859936	0.00136559	0.004317223	0.001829295	0.077419647	0.74079681	0.009622679
6	1550	20	96.489258	2.6756408	0.001267925	0.004164578	0.001833297	0.075813357	0.7423709	0.009641954
7	1550	20	96.699393	2.4652615	0.001193434	0.004059968	0.001837289	0.074634686	0.74394764	0.009660484
8	1550	20	96.908684	2.2551428	0.001134929	0.003990737	0.001841266	0.073987755	0.74552362	0.009677927
9	1550	20	97.116647	2.0456728	0.001088033	0.00394893	0.001845217	0.073985851	0.74709484	0.009693744
10	1550	20	97.322603	1.8373969	0.001049875	0.003929213	0.00184913	0.074774937	0.74865674	0.009707142
11	1550	20	97.52557	1.6311067	0.001018436	0.00392777	0.001852986	0.076559014	0.75020118	0.009716889
12	1550	20	97.7241	1.427969	0.00099218	0.003941603	0.001856758	0.079634375	0.75171738	0.009721053
13	1550	20	97.916044	1.229714	0.000969824	0.003968032	0.001860405	0.084439449	0.75318915	0.009716608
14	1550	20	98.098232	1.0388885	0.000950174	0.004004261	0.001863866	0.091623994	0.75459308	0.009698867
15	1550	20	98.266138	0.85911358	0.000932015	0.004046946	0.001867057	0.10212957	0.75589411	0.009660839
16	1550	20	98.413812	0.6951104	0.000914109	0.004091893	0.001869862	0.1172351	0.75704774	0.009592993
17	1550	20	98.534651	0.552018	0.000895373	0.004134186	0.001872158	0.13845804	0.75800288	0.009484504
18	1550	20	98.62345	0.43367443	0.000875257	0.004169131	0.001873846	0.16720944	0.75871888	0.009326852
19	1550	20	98.678725	0.34072436	0.000854041	0.004193683	0.001874896	0.20434356	0.75918304	0.009118212
20	1550	20	98.703121	0.27036657	0.000832673	0.004207138	0.001875359	0.25000096	0.75941282	0.008864441

Table AI-7. Gas composition in mol fraction during oxygen injection

O2, min	T(C)	P(atm)	X-H2(g)	X-CH4(g)	X-C2H2(g)	X-N2(g)	X-HCN(g)	X-H2O(g)	X-CO(g)	X-CO2(g)	X-H2S(g)	X-COS(g)
0	1550	20	0.9501059	0.00630281	8.76683E-05	0.01091002	0.000429397	0.0001912	0.028447	1.4888E-06	0.00328253	3.455E-06
1	1550	20	0.1285686	0.00011833	8.9125E-06	0.00512257	9.38141E-05	0.00107067	0.8625719	0.00186816	0.00041986	9.902E-05
2	1550	20	0.06884369	2.9662E-05	3.64767E-06	0.00341743	4.9021E-05	0.00070256	0.9241374	0.00245274	0.00021882	0.0001033
3	1550	20	0.04759071	1.233E-05	1.90775E-06	0.00259033	3.08647E-05	0.00057155	0.945963	0.00295463	0.00014726	0.0001029
4	1550	20	0.03652888	6.2791E-06	1.09418E-06	0.00209256	2.10091E-05	0.00051348	0.9570965	0.00349897	0.00010993	0.0001012
5	1550	20	0.02969481	3.562E-06	6.55462E-07	0.00175647	1.48977E-05	0.0004896	0.9636949	0.00413238	8.6786E-05	9.901E-05
6	1550	20	0.02503086	2.156E-06	4.0093E-07	0.00151262	1.08125E-05	0.00048658	0.9678715	0.00489321	7.0944E-05	9.643E-05
7	1550	20	0.02163147	1.3599E-06	2.47155E-07	0.00132672	7.95058E-06	0.00049924	0.970532	0.00582549	5.9362E-05	9.363E-05
8	1550	20	0.01903368	8.8081E-07	1.52192E-07	0.00117978	5.88329E-06	0.00052597	0.9721053	0.00698629	5.0492E-05	9.065E-05
9	1550	20	0.016975	5.7981E-07	9.29677E-08	0.00106042	4.35942E-06	0.00056718	0.9727884	0.00845337	4.3457E-05	8.755E-05
10	1550	20	0.01529455	3.8485E-07	5.5997E-08	0.0009614	3.2215E-06	0.00062493	0.9726391	0.0103358	3.7721E-05	8.433E-05
11	1550	20	0.01388727	2.5587E-07	3.30656E-08	0.00087793	2.36561E-06	0.00070289	0.9716082	0.0127896	3.2939E-05	8.101E-05
12	1550	20	0.01268049	1.6936E-07	1.90295E-08	0.00080679	1.72035E-06	0.0008067	0.9695397	0.01604133	2.8876E-05	7.761E-05
13	1550	20	0.01162114	1.1095E-07	1.06104E-08	0.00074576	1.23506E-06	0.00094451	0.9661497	0.02042218	2.5366E-05	7.414E-05
14	1550	20	0.01066819	7.1526E-08	5.69972E-09	0.00069341	8.72865E-07	0.00112742	0.9609894	0.02641256	2.2289E-05	7.058E-05
15	1550	20	0.00978873	4.5137E-08	2.93823E-09	0.00064891	6.06262E-07	0.00136925	0.9534072	0.03468421	1.9553E-05	6.695E-05
16	1550	20	0.00895693	2.7794E-08	1.45415E-09	0.00061185	4.14144E-07	0.00168422	0.942558	0.04609416	1.7095E-05	6.324E-05
17	1550	20	0.00815626	1.6717E-08	6.96685E-10	0.00058205	2.7959E-07	0.00208072	0.9275526	0.06154019	1.4871E-05	5.945E-05
18	1550	20	0.00738309	9.8922E-09	3.28903E-10	0.00055919	1.88295E-07	0.00255252	0.907799	0.08162423	1.2864E-05	5.56E-05
19	1550	20	0.00664637	5.8286E-09	1.56521E-10	0.00054256	1.27948E-07	0.00307528	0.8833592	0.1063006	1.1069E-05	5.172E-05
20	1550	20	0.00596042	3.4614E-09	7.65354E-11	0.00053103	8.85143E-08	0.00361486	0.8549695	0.1348537	9.4863E-06	4.784E-05

Table AI-8 weight of species in g in metal phase during oxygen injedtion

O2, min	T(C)	P(atm)	g-Fe	g-C	g-H	g-N	g-Ni	g-O	g-S	g-V
0	1550	20	10000.003	406.00002	0.70000005	0.89999997	0.19000001	0.23999884	76.999994	0.99999645
1	1550	20	9999.9974	389.6934	0.28736915	0.67260672	0.19000001	8.4506288	76.97293	0.99983395
2	1550	20	9999.9974	367.3963	0.21152832	0.56558696	0.19000001	8.647327	76.962605	0.99977027
3	1550	20	9999.9974	344.84625	0.17693097	0.50837083	0.19000001	8.4809732	76.954941	0.99969437
4	1550	20	9999.9974	322.27974	0.15607659	0.47254355	0.19000001	8.2571608	76.948528	0.99959503
5	1550	20	9999.9974	299.7542	0.14183722	0.4484091	0.19000001	8.0412041	76.942981	0.99946105
6	1550	20	9999.9974	277.29927	0.13140575	0.4316104	0.19000001	7.857179	76.938171	0.99927716
7	1550	20	9999.9974	254.94067	0.12341692	0.4198544	0.19000001	7.7182146	76.934034	0.99902194
8	1550	20	9999.9974	232.70795	0.11711316	0.41180375	0.19000001	7.634789	76.930507	0.99866433
9	1550	20	9999.9974	210.64074	0.11203354	0.40661705	0.19000001	7.618244	76.927557	0.99815441
10	1550	20	9999.9974	188.79442	0.10787569	0.40373068	0.19000001	7.6832015	76.925248	0.99741881
11	1550	20	9999.9974	167.24909	0.10442753	0.40274251	0.19000001	7.8501457	76.923517	0.99634242
12	1550	20	9999.9974	146.12246	0.10152869	0.40333975	0.18999995	8.1488961	76.922394	0.99474438
13	1550	20	9999.9974	125.58857	0.099046489	0.40524831	0.18999995	8.6236559	76.921913	0.99234045
14	1550	20	9999.9974	105.90285	0.09685937	0.40818875	0.18999995	9.3400226	76.92217	0.98868896
15	1550	20	9999.9974	87.427202	0.09484595	0.41183512	0.18999995	10.393158	76.923132	0.98312972
16	1550	20	9999.9974	70.631368	0.092884216	0.41578432	0.18999995	11.912461	76.924928	0.97476054
17	1550	20	9999.9974	56.022714	0.09086883	0.41956656	0.18999995	14.051707	76.927525	0.96255496
18	1550	20	9999.9974	43.972738	0.088747287	0.42273209	0.18999995	16.954324	76.93086	0.945703
19	1550	20	9999.9974	34.528645	0.086547589	0.42498339	0.18999995	20.70796	76.934804	0.92402994
20	1550	20	9999.9974	27.39189	0.084361377	0.42624147	0.18999995	25.32857	76.939069	0.89809103

Appendix II

Second Draft of Detailed Experimental Test Plan

MEFOS

Box 812, 971 25 LULEÅ

Dokument:	Försöksprogram	*Reg nummer:*	
Fo-uppgift:		*Datum:*	2003-03-20
Konto:		*Rev datum:*	
Ämnesomr:		*Avdelning:*	MM

HYMELT PILOT PLANT TESTS AT MEFOS

PROGRAMME CAMPAIGN 1

by

Sten Ångström

Projektledare:	Nils-Olov Lindfors	*Sekr:*	acj
Distribution:			

Background

This programme describes planned activities in the HyMelt project at Mefos during the period 2003-02-25 to 2003-06 30

The activities refer to tasks and subtasks in a work program stated in KK01005K:

Subtask 1 Thermodynamic calculations

The work will be executed according to plan

Subtask 2 Design and construction of lances for injection and blowing

The work will be executed according to plan

Subtask 3 Design and construction of an oil feeding system

The work will be completed 1 September

Subtask 4 Design and construction of reactor shell for high pressure operation

The work will be executed according to plan

Subtask 5 Design and construction of water injection system

The activity has lower priority. Final decision will be taken later.

Subtask 6 Preparation work for atmospheric pressure operation

The work will be executed according to plan except for carbon and coke. Oil feed will test in hot condition. Full evaluation including chemistry, mass and heat balances etc will be made in a coming campaign dedicated for oil.

Detailed description of the work follows below in the subsequent chapters.

Subtask 7 Cold tests for atmospheric pressure test

See Subtask 6

Subtask 8

See Subtask 6

Subtask 9

See Subtask 6

Subtask 10 to 15

In accordance with the work programme the activities are planed to be performed after 030630.

Experimental objectives

In Mefos pilot converter pulverized coal, pet-coke and oil shall be feed to an iron melt by top lance injection. The injection period, recarburisation and hydrogen production follows by oxygen blowing in a decarburisation and CO-gas production period.

The objectives are to determine:

- Gas composition
- Dust amount, size distribution and composition
- Sulphur distribution
- Productivity limitations, yields, carbon dissolution etc
- Hot test of HyMelt equipments
- Practical operational experiences
- Heat and mass-balance evaluations

Time schedule and Scope of work

The test will be performed in June 5,6,10,11,12 and 13 2003.

Day 1	Coal tests
Day 2	Coke tests
Day 3	Coal tests
Day 4	Coke tests
Day 5	Rearranging lance system etc for oil injection
Day 6	Oil injection tests
Day 7	Oil injection tests

Operation will be on daytime from 06:00 to 18:00.

Preparation work

Preparation of MEFOS test units and equipment for HyMelt trials and assembly of HyMelt equipment:

EAF refractory work

Universal Converter

- Refractory work
- Installation of bottom purging elements
- Rearranging process gas system

Assembling lances and injection system
- Material injection system including 3 m^3 dispenser on load cells

Assembling material handling system including hopper load cells
- Cooling scrap
- Lime

Oil injection system including barrel recharging, heated tank, pump, flow control and lance

Manual addition of

- Aluminium bars
- Vanadium
- Nickel
- Ferrosulphur
- Dolomite

Measurements

- Gas and dust sampling lance from converter atmosphere
- Set up of standard gas analysers and mass spectrometer of process gas
- Dust sampling in combusted gas for determination of composition and load
- Overhead crane weighing scale
- Metal sampling probes and melt temperature system
- Combusted gas analysis and flow rate measurements

– Process control set up

– Hydrogen flow control

Ladle refractory work

The bag filter line will be used in parallel with the wet venturi.

Raw materials and gas

Pig iron 36 ton

Coal, Illiois #6 in big bags 4,5 ton 19 ton

Pet-coke in big bags 4,5 ton 10 ton

Oil in barrels 4,5 ton 6,2 ton

Lime 10-20 mm 5 ton

Dolomite 10-20 mm 1 ton

Cooling scrap small pieces SSAB 2 ton

Aluminium bars 200 kg

Ferrosulphur 1000 kg

Ferrovanadium ? kg

Nickel ? kg

Hydrogen supply from gas bottle ? kg

Measurements and data logging

The composition of ingoing materials will be analysed before start of tests.

Coal complete elemental analysis, particle size

Coke complete elemental analysis, particle size

Oil complete elemental analysis

Lime complete elemental analysis according to the supplier

Cooling scrap complete elemental analysis according to the supplier

Aluminium bars complete elemental analysis according to the supplier

Ferrosulphur 10 – 30 mm complete elemental analysis according to the supplier

Ferrovanadium 10 – 30 mm complete elemental analysis according to the supplier

Nickelcomplete elemental analysis according to the supplier

Dolomite lime 10 – 20 mm complete elemental analysis according to the supplier

Following measured data will be collected and stored in a process computer. The software platform to be used is LabView.

Continuous measurements:

Gas supply: range

Oxygen to lance 0 – 20 m^3n/min

Nitrogen bottom purging 0 – 1 m^3n/min

Nitrogen material transport 0 – 1 m^3n/min

Combusted gas

Flow rate, venturi 0 – 20000 m^3n/h

bagfilter 0 – 5000 m^3n/h

Composition:

CO 0 – 1%

CO_2 0 – 5%

O_2 0 – 23%

SO_2 0 – 0,5%

Materials

Dispenser weight 0 – 3000kg

Bin weights

Cooling scrap 0 – 1000 kg

Lump lime 0 – 1000 kg

Oil feed 0 – 15 l/min

Non continues measurements

Metal temperature 0 – 1800 °C

Metal composition

Process gas composition

	Decarb.	Carburisation
CO	0 – 100%	0 – 20%
CO_2	0 – ?%	0 – ?%
H_2	0 – 5%	0 – 100%
H_2S	0 – 0,5%	0 – 2%
COS	0 – 10ppm	0 – 10ppm
CH_4	0 – 0,1%	0 – 2%

Special measurements and sampling not recorded on the process computer:

Metal weight, charging and tapping

Analysis of sampled metal and slag

Poured slag weights

Dust sampling in converter for composition analysis

Dust sampling in combusted gas for composition analysis and load

Manual additions

Process control

During operation all measured parameters can be displayed in real time.

In addition the most essential process parameters are calculated on line for supervising.

1. Material injection flow rate
2. Gas flow rate
3. Carbon balance for recarburisation yield
4. Oxygen balance for oxygen yield during decarburisation

Experimental procedures

Before start of tests the converter and the transfer ladle will dried and preheated.

One test day is planned for 2 hours of melting, 10 hours for operation in the converter. One test cycle is estimated to 1 hour.

For each day:

1) Pig iron is melted and adjusted to hot metal quality:

%C	4 – 4,5
%Si	0,2 -0,5
%Mn	0,2 – 0,5
%S	~0,020
%P	~0,040

2) The hot metal is tapped into a transfer ladle and if necessary, the furnace slag is skimmed off before weighing.

Tapping temperature ~1450^{o}C'

During tapping the metal will be alloyed with vanadium and nickel

%V	?
%Ni	?

3) The hot metal is charged into the converter.

4) Sampling and temperature measurement

Adjusting of sulphur composition to ~1%

Addition of aluminium bars or cooling scrap, target temperature ~1300^{o}C.

Slag skimming if necessary

5) Oxygen blowing to ~0,5%C, ~10 m^3n O_2/min.

Slag former addition after ignition.

CaO/SiO_2 ~?

%MgO~?

Sampling, temperature measurement, adjustment of temperature to ~?°C.

6) Injection of coke or coal to 4% carbon injection flow rate ~10 kg/min.

The procedure 4) – 6) are repeated for approximately 10 times.

During the days separate sulphur refining test shall be made by hydrogen purging through the bottom of the converter for 10 minutes with ? ln/minute.

The melt is tapped into transfer ladle and before casting in sand bed the weight is registered.

Controlled parameters to vary during operation are:

- Temperature, high ? °C
  low ? °C
- Feed, high ? kg/min
  low ? kg/min
- Transition carbon level, high ? %
  low ? %
- Sulphur content, high ? %
  low ? %

Staffing

Raw material handling, tractor driver 1

EAF operator 1

Material, oil injection 1

Crane operator and ladles 1

Converter operator 1

Metal sampling, temperature

Measurements and manual additives 1

Dust sampling combusted gas1

Process gas sampling 1

Leco analysis 1

Instrumentation and computer 2

Researcher 2

Account numbers

SAFETY